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Estrella Forster, Ph.D.

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Naval Air Warfare Center Aircraft Division
22347 Cedar Point Road, Unit #6
Patuxent River, Maryland 20670-1161

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The use of naval platform is continuing to undergo downsizing and therefore those aircrew and aircraft who/which remain are becoming more valuable. Additionally, “pilot error” continues to be the principal cause of aircraft accidents and incidents leading to fatalities or losses over 1 million dollars (Class A mishaps.) Indeed, Controlled Flight into Terrain (CFIT), Loss of Situational Awareness (LSA), Failure of Aircrew Coordination (FAC), Mid-Air Collisions (MAC), spatial Disorientation (SD), and Altered States of Awareness (ASA) from simple confusion to “almost” and frank G-induced loss of consciousness (A-LOC and G-LOC) account for over 50% of material losses. These losses may not be an error in the part of the pilot but rather the result of a physiologic event over which the pilot has essentially no control and limited protection.

Accident investigation boards who identify a mishap cause(s) necessarily select it from a chain of events. The finding of “pilot error” may then be an attractive solution whenever the data available does not identify equipment, engine, or other component failure as the cause of the accident. This is probably especially true given the political environment under which these boards may be constrained. Moreover, the pilot may not be around to explain him/herself. Finally, certain accidents and incidents may very well be due to ASA but misclassified as LSA, SD, FAC, MAC, etc. for lack of relevant data. This data being the phsychophysiologic state of the pilot.

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SAFETY OF FLIGHT: THE PHYSIOLOGIC ASPECT OF THE WEAPON SYSTEM

Estrella M. Forster, Ph.D.

Naval Air Warfare Center, Aircraft Division
Crew Systems Technology Department
48110 Shaw Rd., Bldg. 2187 Unit 5
Patuxent River, Maryland, 20760 USA

Introduction

The user of naval platforms is continuing to undergo downsizing and therefore those aircrew and aircraft who/which remain are becoming more valuable. Additionally, "pilot error" continues to be the principal cause of aircraft accidents and incidents leading to fatalities or losses over 1 million dollars (Class A mishaps.) Indeed, Controlled Flight into Terrain (CFIT), Loss of Situational Awareness (LSA), Failure of Aircrew Coordination (FAC), Mid-Air Collisions (MAC), Spatial Disorientation (SD), and Altered States of Awareness (ASA) from simple confusion to "almost" and frank G-induced loss of consciousness (A-LOC and G-LOC) account for over 50% of materiel losses. These losses may not be an error in the part of the pilot but rather the result of a physiologic event over which the pilot has essentially no control and limited protection.

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Background

It has been reported that over the last 10 years (1986-1996), 350 accidents and incidents involved one or a combination of LSA, SD, FAC, and GLOC (1). Sixty-six accidents have been directly blamed on these events. This figure translates into significant financial and intangible costs. Twenty-two to 25% of pilots have reported A-LOC in-flight (2). The aviation community has attempted to address these errors by implementing improved training and advancing intelligent state-of-the-art technology. Unfortunately, this approach has not led to the effective reduction of aircraft accidents and incidents because the originating factor of these flight mishaps is most likely a psychophysiologic event. This event may be fatigue, apathy, euphoria, dehydration, loss of vision, reduced blood flow, reduced oxygen saturation, loss of motor control, intellectual overload, auditory hallucinations, respiratory symptoms, or a combination thereof caused by the environmental stress typical of tactical air operations: *altitude, thermal, and acceleration exposure*.

As a result, the operator may no be able to see, orient, concentrate, discern, hear, understand, move, decide, react, etc. That is, the operator does not suddenly become dumb or refuses to consult cockpit instrumentation; rather, s/he suffers a physiologic insult against which s/he may have no protection. Indeed, training becomes irrelevant when a pilot is suffering from amnesia, is confused, is experiencing myoclonic or mimic convulsions or, in the case of G-LOC, is simply reviewing the contents of a dream (3). For example, apathy is not an uncommon symptom of ASA. Moreover, protection is especially not available if the equipment meant to provide it ignores the life it's presumed to protect. For example, G-LOC in flight results in loss of aircraft (A/C) control. A/C +Gz input is not likely at this stage. Hence, when the pilot most needs the protection of a g-suit, the g-suit is not activated. Finally, G-LOC has occurred in spite of Combat Edge; a g-ensemble that is considered a panacea to G-stress. Similar constructs may be formulated for LSA, SD, FAC, etc.

Given that the latest technology addresses everything but the psychophysiologic aspect of the weapon system, "pilot error," as described above, will not be eliminated until the RDT&E community reassesses its approach. One

approach that has become increasingly attractive is that of eliminating the aircrew from the aircraft in the form of Uninhabited Air Vehicle (UAV) programs. Unarguably, the experience, gray matter, and adrenaline of the human operating the aircraft are fundamental for the success of most air combat missions.

A Unified Weapon System

It has become imperative to address the psychophysiologic aspect of the weapon system by incorporating the pilot in "the loop." There are efforts addressing this goal. For example, the Israeli Ministry of Defense (IMOD) has been developing a helmet with sensors that monitor brain wave activity so that pilot state is assessed. This helmet has been tested in flight. Russian Systems Corporation has developed a system to assess pilot state. Other programs mainly supported by the US Army to address Combat Medicine concerns are also under development. One program that considers human physiology the primary aspect of its approach is the US Smart Aircrew Integrated Life Support System (SAILSS) effort. SAILSS exemplifies network centric warfare by producing a *Unified Weapon System* that addresses three aspects of the air operational environment: the aircraft, the cockpit, and the pilot. This synergistic approach is accomplished by assessing pilot status, optimizing said status via Life Support Equipment (LSE), and communicating such status to the pilot and the remainder of the weapon system. For example, ground collision avoidance, escape, and other emergency components.

Addressing the psychophysiologic aspect of the weapon system not only reduces so-called "pilot error" but also optimizes pilot performance for improved mission effectiveness. The ability to deploy, maneuver, and engage an adversary is highly dependent on the pilot's state as it refers to awareness, fatigue, and cognitive load. These parameters are a function of environmental stress. Reduction of this stress via SAILSS will result in a weapon system that can "accurately locate and identify the enemy, command and control friendly forces, precisely attack key enemy forces or capabilities, and accurately assess the level of success." SAILSS will afford a continuous availability of personnel and their optimized performance. SAILSS will mitigate personnel risk and enhance their capabilities in an operating environment. The SAILSS technology will result in reduced casualties, increased mission duration, and faster turnaround time, which ultimately reduces manpower costs and saves lives & aircraft.

SAILSS also offers widespread applications for both the military and civilian sectors, specifically in the medical and human factor fields. For example, SAILSS allows Measures of Effectiveness and Performance be assessed and ultimately result in appropriate control algorithms for adaptive automation whenever the psychophysiologic state of the aircrew or other user is below acceptable levels. Finally, SAILSS real time assessment of pilot (or other user) status offers a wide variety of training opportunities. These characteristics make the system a wise RDT&E investment with high resource-leveraging potential. SAILSS ultimately unifies the cockpit, aircraft, and pilot into a lethal and more survivable weapon system. The SAILSS technology enables pilots to approach the aircraft structural envelope, providing a significant tactical advantage in air combat. SAILSS ensures the pilot's mental acuity, physical performance, endurance, and ability to deal with battle stress is optimized. In essence, SAILSS ensures the pilot remains in control.

Technical Approach

SAILSS addresses the psychophysiologic aspect of the weapon system. The pilot is a psychophysiologic being; a conglomerate of viscera (brain, heart, lung, etc.). These viscera govern his/her motor and cognitive performance. Protecting these viscera by assessing and optimizing their status is essential. SAILSS approach is innovative in that it effects an indispensable "electronic handshake" between the commander and his/her aircraft. Integration, not just involvement, is a prime factor of the SAILSS goals. This integration includes all weapon systems i.e., vehicle management, aircraft & pilot recovery, escape, and life support.

SAILSS advanced technologies include sensor and other components capable of receiving and processing large amounts of data real-time in an inhospitable environment. Technologies that monitor pilot state are based on input from unobtrusive and lightweight physiologic microsensors embedded in the helmet, mask, and a torso undergarment. These sensors include those monitoring brain, heart, thermal, and respiratory function. Input to SAILSS also includes aircraft and cockpit status (G, altitude, attitude, LSE, stick input, etc). Based on this input, SAILSS optimizes pilot state by activation of protective equipment (i.e., LSE) addressing 1) acceleration, 2)

altitude, and 3) thermal stress. The program is currently focusing on the acceleration environment. SAILSS is currently integrated with Navy Combat Edge (NCE). The current components of SAILSS include 1) a host computer which functions as an interface with the operator of the system, 2) physiologic sensors described above, 3) a signal conditioning system which processes physiologic data originating from the pilot and communicates it to 4) a data acquisition and control system (VME) which controls the appropriate LSE. SAILSS current control components include Breathing Regulation Anti-G (BRAG) and anti-G Electronic Control Unit (ECU). The altitude environment is being addressed through a joint effort with the USAF (Sharp Edge). The thermal environment is being addressed by a concurrent Navy effort (HAILSS) described below.

The ultimate SAILSS will be composed of a miniaturized VME box incorporating components described above and a complete NCE system with micro-sensors transparent to the user. To arrive at this goal, SAILSS has and will be integrated with aircraft systems and demonstrated in various simulators including static (dome, altitude chamber, and thermal chamber) dynamic (human centrifuge) and in flight.

Incorporation of the Pilot's Physiology in Aviation Systems

The SAILSS system is integrated with the current NCE and has potential for integration with other ensembles. For example, the Helicopter Aircrew Integrated Life Support System (HAILSS). HAILSS is an USN program that provides protection against thermal stress, CB threat, immersion, and fire in a single 2-layered impermeable ensemble. The HAILSS includes an Advanced Portable Air Conditioning System (APACS) which cooled or warmed airflow may be regulated. HAILSS is modular in its approach in that it may accommodate the CB and non-CB environments as required. Current & developing helmets may also be integrated in its design. Hence, SAILSS is projected to a) integrate with this thermally controlled encapsulating garment and b) taking advantage of APACS technology for its own tactical applications. The future integration of SAILSS with HAILSS demonstrates the wide applicability of the SAILSS in that it supports commonality across the military services and therefore implies a reduction in cost.

SAILSS considers the following platforms for potential integration: The F-18, Joint Strike Fighter (JSF) and other fighter aircraft in USN/USMC and USAF inventory. The system also offers opportunities for integration with other programs including those addressing medical issues in the US Army and civilian sector. In accordance to the US DoD Science and Technology strategy, SAILSS also offers to maintain our technological superiority by its accelerated development process. The program's schedule demonstrates a rapid technology transition from earliest S&T concepts to the operational forces.

The integration of SAILSS described above includes addressing joint efforts such as those of the Joint Protective Air Crew Ensemble (JPACE), the Joint Service Aircrew Mask (JSAM), and the Joint Strike Fighter programs. For example, SAILSS goals include altitude protection to 70 K feet (get-me-down), high onset-rate acceleration protection > 9 +Gz, and optimization of body temperature. SAILSS integration also includes vehicle management systems, ground-collision avoidance systems (GCAS), escape, NCE, altitude protection systems, etc. In addition, SAILSS is also a component of the Advanced Network Guidance and Emergency Logic (ANGEL) program. This program integrates several technologies that will allow full protection of the weapon system. Aircraft modification will be minimized in that SAILSS will be potentially integrated with the US Navy's Mobile Integrated Data and Diagnostic Analysis (MIDDAS) program. This program's efforts concentrate around the miniaturization of computer electronics so that the VME may be man-mounted.

The SAILSS team demonstrates a strong technology base. This team includes a variety of national and international experts from government, industry, and academia. Moreover, the team is focused on the interests of the proposed user and the maintainer of the system. This strategy demonstrates purposeful jointness and is affirmed by the SAILSS Defense Technology Objective (DTO) HS.26.02. SAILSS also addresses the current fleet directives in continuing *"the Aircrew Integrated Life Support System (AILSS) program...the AILSS provides fully integrated aircrew protection against ... extreme temperature exposure, and high-G threats..."*

SAILSS also aids in building a common industrial base by utilizing commercial practices, processes, and products, and by developing, whenever possible, technology that can be the base for both military and commercial products

and applications. SAILSS also fosters dual use technology development, ensures exploitation of commercial technology, and nurtures technology transfer among laboratories, industry, and universities. Technology transfer opportunities are vast. For example, SAILSS offers applications opportunities in triage, occupational health, and hyperbaric medicine.

The scientific/engineering risk associated with the SAILSS technology is the utilization of sensors that are unobtrusive and transparent to the pilot. These sensors are also to be able to withstand the high performance aircraft environment in normal, combat, and emergency operations. Integration with the aircraft and cockpit also presents challenges in that this integration is to go beyond involvement and effectively establish appropriate interfaces between the various systems. For example, the information provided by SAILSS may vary in accordance to system requirements (aircraft, cockpit, LSE) and take many forms as to its presentation in the various current and developing displays. SAILSS goal is to incorporate the pilot "in-the-loop." As such, all aspects of this loop must be addressed.

The programmatic risk associated with this technology is its acceptance by the user and the platform in which the system will function. Establishing contact early in SAILSS development is key if the system is to demonstrate its value. Incorporation of the user and the maintainer's input into the SAILSS design will also facilitate instituting a sense of ownership. This goal can only secure its implementation in the fleet and the resulting benefits; the reduction of loss of life and aircraft and the optimization of aircrew performance for enhanced mission effectiveness.

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